MAP READING
FOR
AVIATORS
INCLUDING
AERIAL NAVIGATION

BENSON

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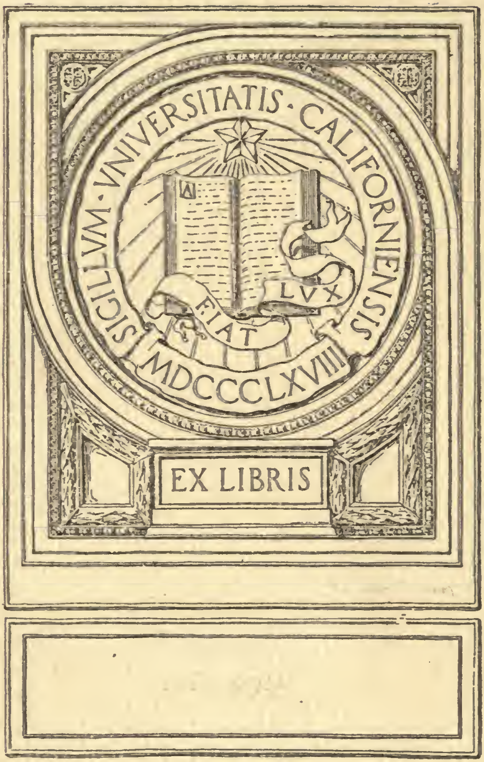
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MAP READING FOR AVIATORS

WITH A CHAPTER ON AERIAL NAVIGATION

BY

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This little book has been prepared with a view to providing a brief reference in Map Reading and Aerial Navigation for Aviation Students in the United States Army.

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CONTENTS

CHAPTER I

MAPS

A Map is a graphical representation of a portion of the earth's surface. Information of the natural and artificial features is conveyed to the reader by means of lines, symbols, words, and abbreviations. It is drawn to scale—that is, there is a definite relation between the space on the map and the ground distance represented.

The amount and character of the information given on a map depend upon the use to which the map is to be put and the size—or the scale—of the map. It is obvious that more detail can be shown on a large than on a small map of the same area. The features to be left off the map are determined by the use which is to be made of it. For instance, the ordinary County Map shows only property lines, streams and dwellings. Its purpose is to enable the County Clerk to keep track of the taxes, etc., and it is immaterial to him whether there is a hedge or barbed wire fence between John Brown's property and William Smith's. The map found in a railroad time-table does not show types of bridges along the line, or whether the highways are metaled or not, but it does show the sequence of the towns and villages passed thru, the large streams crossed, and connections which can be made with other railroads. Maps of these two types rarely show differences in elevation. That information is not essential to their purpose. The topographic map, on the other hand, goes into detail as to the exact form of the ground, the location of buildings, fences, highways, railroads, and other natural and artificial features.

A military map is an elaborate topographic map. There is nothing on the surface of the earth which does not have its military significance, and therefore a good military map shows all the information which is compatable with its size. For instance the "Trench" or "Position" Map (See page 15) shows, first, the exact form of the ground—hills, valleys, ridges, etc., whether the railroads are single or double track, steam or electric; whether the highways are metaled, ordinary county roads, or simply trails; whether the fences are stone, hedge, barbed wire, smooth wire, rail, or board; whether the bridges are truss, arch, suspension, ponton, foot or aqueducts, whether the buildings are dwellings, barns, factories, post offices, churches, telegraph offices, or military headquarters; where the telephone and telegraph lines are; the electric power transmision lines; whether the streams are fordable; where the woods are; where the different military units are located, etc., etc.

However, all maps have a military use. A map which shows only large towns, streams, railroads, and highways will be useful to the aviator in cross-country work, and to the staff in working out strategic moves, because the details of the movement of small bodies of troops must be left to the officer in immediate command in any event. Even the county map will enable a commander to make plans for concentrations of bodies of troops.

The term "Map" implies an accurately made drawing from a survey in which the distances and directions have been carefully measured with instruments. The name "Sketch" is given to the map which has been hastily made in the field by measuring the distances by some crude method such as counting paces, timing the trotting of a horse, or counting the revolutions of a wheel. Sketches are rarely used in modern warfare, except in minor operations. Topographic maps obtained in time of peace are converted into military maps by the use of aerial photography and data gotten by secret agents in the enemy's country. Extreme accuracy may be gotten from aerial photographs when the altitude of exposure is known, the focal length of the lens, and the size of the negative. Even when this data is missing, if two or more features can be identified from a good map, the relative distances of other features may be easily and accurately filled in.

"Map Reading," or the art of translating and understanding the information given on maps, may be said to consist of only four things: First, the scale, or relation between the size of the map and the ground represented; Second, the symbols or conventional signs used to represent different features; Third, the representation of differences in elevation or contour of the earth, and Fourth, the direction.

Each of these problems will be taken up in turn.

CHAPTER II

MAP SCALES

THE DISTANCE shown on a map between two points is always the horizontal distance. The map is made as tho the observer were vertically above each point. This will be made clearer when the study of contours is reached.

Kinds of Scales

The scale of a map is the ratio between the length of the lines on the map and the length of the lines they represent on the ground.

There are three ways of showing the scale of a map: The Graphical Scale; the Words and Figures Scale; and the Natural Scale or Representative Fraction, commonly spoken of as the "Scale" or the "R. F."

The Graphical Scale

The Graphical Scale is the most common and best known, and usually appears in conjunction with one of the other methods. It is simply a line or graph marked off in some common units, such as miles, yards, meters, kilometers. In Figure 1, the distance from A to B is 200 yards. It means that a space A-B on the map represents 200 yards on the ground. Similarly CD is 540 yards.

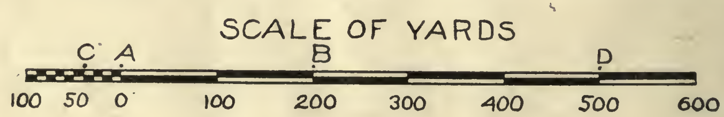


Figure 1.

The "Words and Figures" Scale

When speaking of the scale of a map or calculating distances on it the "Words and Figures" method is usually used. "6 inches = 1 mile" obviously means that 6″ **on the map** represent a distance of one mile on the ground. "10 cm. = 1 km." (See Table II on page 11) means that a space of 10 cm. **on the map** represents a distance of one kilometer on the ground. It is awkward for a man trained in the English system to use a map in the Metric system, and vice versa, and for that reason most military and topographic maps have their scales given in the "Natural Scale" or "Representative Fraction" method.

The "R. F."

The "Natural Scale" or "R. F." of a map is a fraction, the denominator of which shows the number of times the line on the map is contained in the line it represents on the ground. In other words, it shows what fraction of the ground the map is. The R. F. does not depend upon the system of units used. It may be found by writing a fraction having in the numerator the number of units on the map and in the denominator the number of the **same units** on the ground, which is represented by the numerator. For convenience this numerator is usually written as 1.

Changing Words and Figures to R.F.

If the scale of a map is given as: "6 inches = 1 mile," the R. F. may be found as follows: (One mile contains 63,360 inches)

$$\frac{\text{6 inches on map}}{\text{1 mile on ground}} = \frac{\text{6 inches on map}}{\text{63360 inches on ground}}$$

$$= \frac{\text{6 units on map}}{\text{63360 units on ground}} = \frac{1}{10560} \text{ or the R. F. is } \frac{1}{10560},$$

which means that the lines on the map are 1/10560th as long as the lines they represent on the ground. If one line is

1/10560th as long as another it is easy to see that it is immaterial whether you measure them in inches, feet, miles, yards, centimeters, meters, or kilometers. As long as you measure then both **in the same** units, the result for one will be 10560 times as large as the result for the other.

If "4 inches = 1 mile," the R. F. is:

$$\frac{\text{4 inches on map}}{\text{63360 in. on ground}} = \frac{\text{4 units on map}}{\text{63360 units on ground}} = \frac{4}{63360} = \frac{1}{15840}$$

or the lines on the map are 1/15840th as long as the lines they represent on the ground.

If the scale is given as "10 centimeters = 1 kilometer," the R. F. is, since there are 100,000 centimeters in 1 kilometer,

$$\frac{\text{10 cm. on map}}{\text{1 kilometer on ground}} = \frac{\text{10 cm. on map}}{\text{100,000 cm. on ground}} =$$

$$\frac{\text{10 units on map}}{\text{100,000 units on ground}} = \frac{10}{100{,}000} = \frac{1}{10{,}000}$$

or the lines on the map are 1/10000th as long as the lines they represent on the ground.

If the scale is given "1 millimeter = 10 meters," the R. F. is found in the same manner. There are 1000 millimeters in one meter.

$$\frac{\text{1 mm. on the map}}{\text{10 m. on ground}} = \frac{\text{1 mm. on the map}}{\text{10,000 mm. on ground}} =$$

$$\frac{\text{1 unit on the map}}{\text{10,000 units on the ground}} = \frac{1}{10{,}000} = \text{R. F.}$$

Changing R. F. to Words and Figures

When the scale is given in the R. F. form, it is usually necessary to change it to the "Words and Figures" form before reading the map. Most of us would have difficulty in imagining 21120 inches on the ground but when we know it is 1/3 of a mile it is easy. Therefore, if the scale is given as $\frac{1}{21120}$, it will be convenient to know the number of inches on the map which represents one mile on the ground. Remembering that to find the R. F. from the "Words and Figures" scale, the number of inches on the map which represented one mile on the ground was placed over the number of inches actually in a mile, the "Words and Figures" scale can be found from the R. F. by finding the number, which, when placed over 63360, will give a fraction which may be reduced to the given R. F.

Let X = the number of inches on the map which represents a mile on the ground. Then

$$\frac{1}{21120} = \frac{X}{63360} \text{ or } 21120\ X = 63360 \text{ and } X = \frac{63360}{21120} = 3$$

which means that 3 inches on the map represent a mile on the ground.

If the R. F. is 1/7920:

$$\frac{1}{7920} = \frac{X}{63360} \qquad X = \frac{63360}{7920} = 8, \text{ or 8 inches on the map}$$

represent one mile on the ground.

If it is desired to have the scale in the Metric system, remember that to find the R. F., the number of centimeters on the map which represented one kilometer on the ground was placed over the number of centimeters actually in a kilometer and the fraction reduced.

Given a scale of 1/20,000. To find the number of centimeters on the map which represents one kilometer on the ground:

Let Y = the number of centimeters. Then:

$$\frac{1}{20000} = \frac{Y}{100000}, \text{ from which } Y = \frac{100\ 000}{20\ 000} = 5, \text{ or 5 centi-}$$

meters on the map represent one kilometer on the ground.

Reduced to simple terms, the rules become,

(1) TO FIND THE NUMBER OF INCHES ON THE MAP WHICH REPRESENTS A MILE ON THE GROUND FROM THE R. F., DIVIDE 63360 BY THE DENOMINATOR OF THE R. F.

(2) TO FIND THE NUMBER OF CENTIMETERS ON A MAP WHICH REPRESENTS ONE KILOMETER ON THE GROUND FROM THE R. F., DIVIDE 100,000 BY THE DENOMINATOR OF THE R. F.

Since the R. F. is independent of the system of units used, it offers the most convenient method of changing scales from the Metric to the English system and back. If a map is made in the Metric system it will be difficult for a man trained in the English system to read the scales in centimeters, meters, and kilometers. A single operation will change the scale to "Words and Figures" in the English system, and then a graphical scale may be easily constructed.

Changing from Metric to English Scale

Suppose the scale is given as "10 centimeters = 1 kilometer." Reducing to the R. F.:

$$\frac{10\text{ cm.}}{1\text{ km.}} = \frac{10\text{ cm.}}{100{,}000\text{ cm.}} = \frac{1}{10000}$$

Having the R. F. proceed in the manner described above to find the number of inches on the map which represents one mile on the ground:

$$\frac{1}{10000} = \frac{X}{63360} \qquad X = \frac{63360}{10000} = 6.33''$$ or 6.33 inches on the map represent one mile on the ground, which for practical purposes of map reading is 6 inches = 1 mile.

Changing from English to Metric Scale

If the scale is given as "3 inches = 1 mile," to find the number of centimeters on the map which represents 1 kilometer on the ground, first, find the R. F.:

$$\frac{3\text{ inches}}{1\text{ mile}} = \frac{3\text{ inches}}{63360\text{ inches}} = \frac{3}{63360} = \frac{1}{21120}$$

Having the R. F. proceed as above for finding the number of centimeters on the map which represents one kilometer on the ground:

$$\frac{1}{21120} = \frac{Y}{100\ 000} \text{ or } Y = \frac{100000}{21120} = 4.73+, \text{ or } 4.73 \text{ centimeters}$$

on the map represent one kilometer on the ground. For ordinary map work this may be called "5 cm. = 1 kilometer."

This method is much simpler and less liable to error than the one of remembering the number of centimeters in one inch and the number of miles in a kilometer, etc.

If there is nothing but a graphical scale on a map and it is in the wrong system, it may be easily transferred to the other system.

For instance, upon measuring a graphical scale, it is found that 0.80 inches on the map represent one kilometer on the ground.

There are 2.54 centimeters in one inch.

Therefore, there are 2.032 centimeters in 0.80 inches.

Or 2.032 centimeters on the map represent 1 kilometer or 100,000 centimeters on the ground.

The R. F. is $\frac{2.032}{100,000} = \frac{1}{49,212}$, and since 1/50,000 is known to be a standard Metric scale, it is probable that the map is made on that scale. Then proceeding as above, Rule 1, we find that 1.26 inches (1¼") on the map represent one mile on the ground.

If a map is in the English system and upon measuring the graphical scale it is found that 10.2 centimeters on the map represent one mile on the ground, to change to the Metric system:

There are 0.4" in one centimeter.

Therefore there are 4.08" or 10.2 centimeters.

Or 4.08" on the map represent 1 mile or 63360 inches on the ground. The R. F. is $\frac{4.08}{63360} = \frac{1}{15529}$. 1/15840 is a standard scale for maps in the English system, so allowing for a slight error in measuring, it is probable that the map is on that scale. Proceeding as above, Rule 2, it is found that 6.32 centimeters on the map represent one kilometer on the ground.

It will be found convenient, when measuring distances by eye, to use yards or meters as units. A mile is 1760 yards long, approximately 1800 yards. Where the scale is 3 inches = 1 mile, 1/21120, (or 5 cm. = 1 km., 1/20000), one inch on the map represents approximately 600 yards on the ground. If the scale is 6 inches = 1 mile, 1/10560 (or 10 cm. = 1 km., 1/10000) one inch on the map equals approximately 300 yards on the ground. The error is probably less than that made by estimating the distance on the ground by eye. The number of meters is a little more than 9% less than the number of yards.

There are a few standard scales for military maps. At the present time both England and the United States have adopted the Metric system for their armies, so the scales given are Metric:

TABLE I

	R. F.	Cm. per KM.	In. per mile.
1. "Siege," "Fortification," or "Local" Maps	1/5000	20	12.67
2. "Infantry," "Position," or "Trench" Maps	1/10000	10	6.34
3. "Artillery" Maps (Sometimes Road Sketches).....	1/20000	5	3.17
4. "Tactical" Maps	1/40000	2½	1.58
5. "Strategical" Maps	1/100000	1	0.63
6. "Emergency" Maps (for Aviation Service)	1/250000	0.4	0.25

TABLE II

10 millimeters (mm.)	=	1 centimeter
100 centimeters (cm.)	=	1 meter
1000 meters (m.)	=	1 kilometer (km.)

25.4 mm.	=	1 inch
2.54 cm.	=	1 inch
1 cm.	=	0.4 inch
1 meter	=	39.37 inches
1 meter	=	about 3¼ feet
1 meter	=	1 yard, 3 inches +
1 kilometer	=	about 1100 yards (1093 yards +)
1 kilometer	=	about 0.6 mile
1⅔ kilometers	=	1 mile.

PROBLEMS ON MAP SCALES

1. The R. F. is 1/316,800. What is the scale in inches per mile?
   Answer, 1″ = 5 miles.

2. The R. F. is 1/200,000. What is the scale in centimeters per kilometer?
   Answer, 1 cm. = 2 km.

3. The R. F. is 1/31,680. What is the scale in inches per mile?
   Answer, 2″ = 1 mile.

4. The R. F. is 1/5280. What is the scale in inches per mile?
   Answer, 12″ = 1 mile.

5. The R. F. is 1/50,000. What is the scale in centimeters per kilometer?
   Answer, 2 cm. = 1 km.

6. The R. F. is 1/10,000. What is the scale in centimeters per kilometer?
   Answer, 10 cm. = 1 km.

7. If the scale is 8″ = 1 mile, what is the R. F.? Ans. 1/7920.

8. If the scale is 24″ = 1 mile, what is the R. F.? Ans. 1/2640.

9. If the scale is 20 cm. = 1 km., what is the R. F.? Ans. 1/5000.

10. If the scale is 5 cm. = 1 km., what is the R. F.? Ans. 1/20,000.

11. A is 4 miles from B. How many inches is A from B on a map whose scale is 5 cm. = 1 km.?
    Answer, 12.68″.

12. X is 10 kilometers from Y. How many centimeters is X from Y on a map whose scale is 4″ = 1 mile?
    Answer, 63 + centimeters.

13. A is 38 inches from B on a map whose scale is 20 cm. = 1 km. How many miles is A from B?
    Answer, 3 miles.

14. X is 40 centimeters from Y on a map whose scale is 6″ = 1 mile. How many kilometers is X from Y?
    Answer, 4.22 kms.

15. A is 4″ from B on a map whose scale is 1/120,000. On another map of the same territory, A is 12″ from B. What is its scale?
    Answer, 1/40,000.

16. X is 36 inches from Y on a map whose scale is 1/21120. On another map of the same territory, X is 6 inches from Y. What is its scale?
    Answer, 1/126,720.

17. A map is 40″ square and represents country 10 miles square. What is its R. F.? Answer, 1/15840.

18. Upon measuring a graphical scale it is found that 0.4″ = 1 km. What is its scale in inches per mile? Answer, 0.633″ = 1 mile.

19. Which is the larger scale, 1/10,000 or 1/50,000? Answer, 1/10,000.

20. M is 24″ from N on a map whose R. F. is 1/633,600. How many miles is M from N? Answer, 240 miles.

21. If the scale is "1 inch = 8 miles," how many kilometers is X from Y if they are 20 centimeters apart on the map? Answer, 101.38 kms.

22. How many inches on the map would represent the distance covered in 20 minutes with a ground speed of 120 miles per hour on a 1/250,000 map? Answer, 10.13 inches.

23. Construct a graphical scale of yards for a map whose R. F. is 1/20,000.

24. Construct a graphical scale of kilometers for a map whose scale is "1 inch = 4 miles."

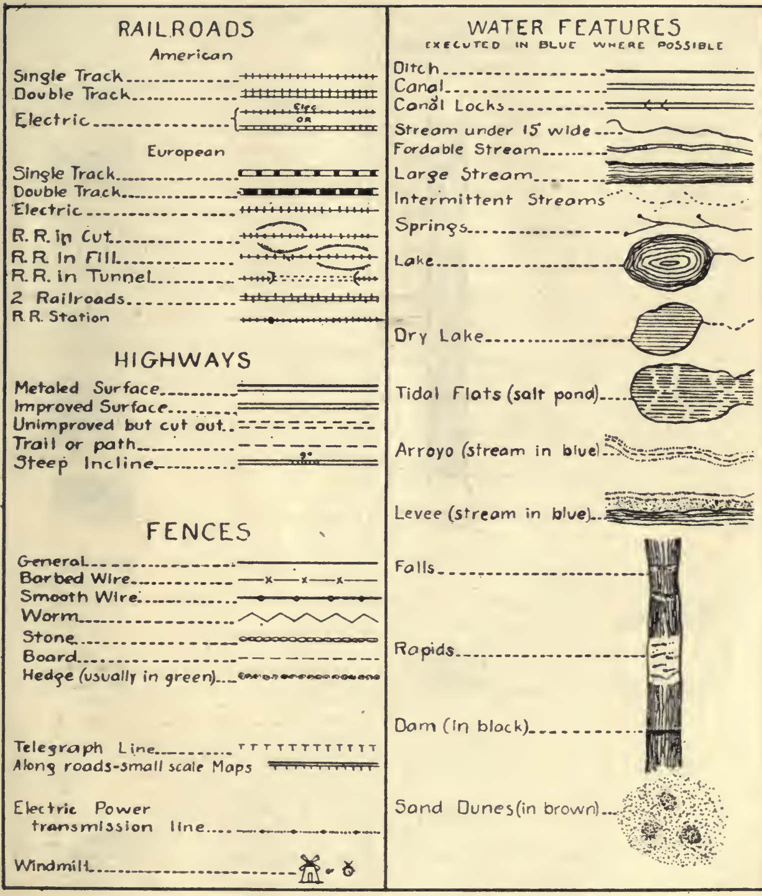
25. Construct a graphical scale of miles for a map whose scale is "1 centimeter = 5 kilometers."

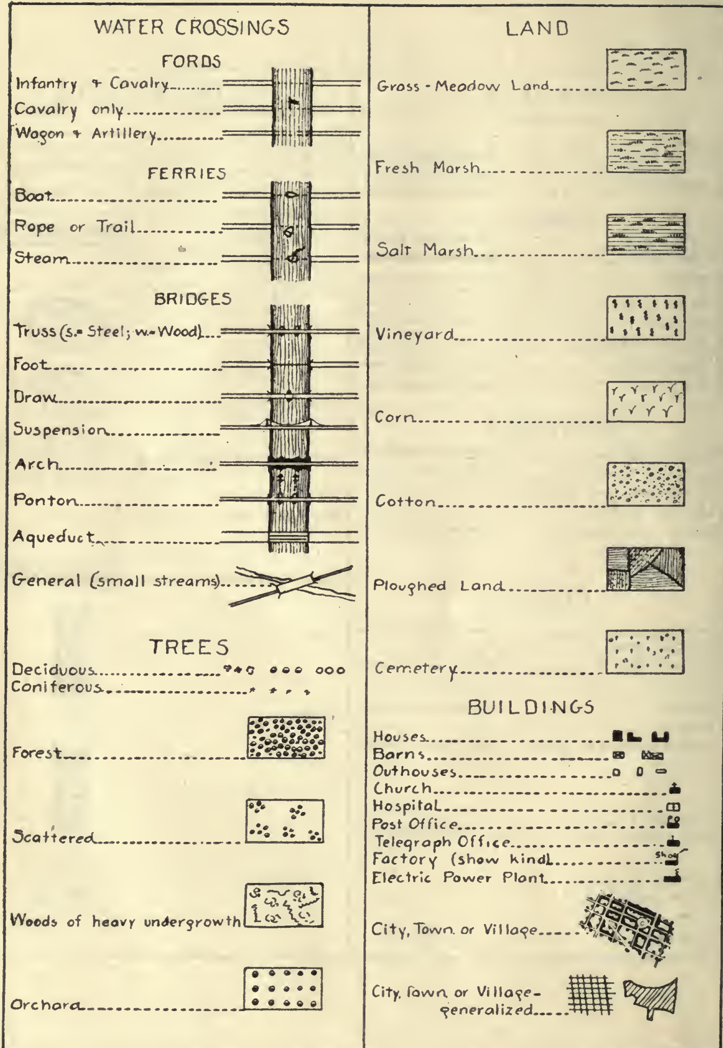
CHAPTER III

CONVENTIONAL SIGNS

THE SYMBOLS used on maps to represent the objects on the ground are called "Conventional Signs." Unfortunately, there is no standard set of conventional signs for all countries, and for some features, different signs are used even in the same country. The following pages give some of the signs in most common use in the United States.

It is necessary at times to draw the signs slightly out of scale. On a small scale map an ordinary house would be a mere speck, and the symbol is usually drawn a little larger so it may be seen easily. This also applies to highways, bridges, etc., etc.


RAILROADS
American
Single Track
Double Track
Electric
Elec
OR
European
Single Track
Double Track
Electric
R. R. in Cut
R. R. in Fill
R. R. in Tunnel
2 Railroads
R. R. Station
HIGHWAYS
Metaled Surface
Improved Surface
Unimproved but cut out
Trail or path
Steep Incline
FENCES
General
Barbed Wire
Smooth Wire
Worm
Stone
Board
Hedge (usually in green)
Telegraph Line
Along roads-small scale Maps
Electric Power transmission line
Windmill
WATER FEATURES
EXECUTED IN BLUE WHERE POSSIBLE
Ditch
Canal
Canal Locks
Stream under 15' wide
Fordable Stream
Large Stream
Intermittent Streams
Springs
Lake
Dry Lake
Tidal Flats (salt pond)
Arroyo (stream in blue)
Levee (stream in blue)
Falls
Rapids
Dam (in black)
Sand Dunes (in brown)


WATER CROSSINGS
FORDS
Infantry + Cavalry
Cavalry only
Wagon + Artillery
FERRIES
Boat
Rope or Trail
Steam
BRIDGES
Truss (s.= Steel; w.= Wood)
Foot
Draw
Suspension
Arch
Ponton
Aqueduct
General (small streams)
TREES
Deciduous
Coniferous
Forest
Scattered
Woods of heavy undergrowth
Orchard
LAND
Grass - Meadow Land
Fresh Marsh
Salt Marsh
Vineyard
Corn
Cotton
Ploughed Land
Cemetery
BUILDINGS
Houses
Barns
Outhouses
Church
Hospital
Post Office
Telegraph Office
Factory (show kind)
Electric Power Plant
City, Town or Village
City, Town or Village - generalized

MILITARY SIGNS

HEADQUARTERS

- Corps — 5 C
- Division — 4 D 9 C
- Brigade — 5 D 4 B 8 C
- Regiment — 23 I

STAFF CORPS

- Adjutant General
- Quartermaster
- Commissary
- Medical
- Ordnance
- Signal
- Engineer

THE LINE

- Infantry in line
- Infantry in column
- Cavalry (as above)
- Mounted Infantry (as above)
- Artillery
- Wagon Train
- Sentry
- Vidette
- Int. Picket
- Cav. Picket
- Inf. Support
- Cav. Support
- Camp
- Trench
- Fort (show true plan if known)
- Redoubt (true plan if known)

- Gun Battery
- Mortar Battery
- Battle
- Good Ldg Place for Airplanes
- Possible Ldg. Place

OBSTACLES

EXECUTED IN RED WHERE POSSIBLE

- Abattis
- Chevaux de frise
- Palisades
- Wire Entanglement
- Demolitions
- Contact Mines
- Controlled Mines
- Mine Crater
- Mine Crater Fortified

AUTHORIZED ABBREVIATIONS

A.	Arroyo
abut.	Abutment
Ar.	Arch
b.	Brick
B.S.	Blacksmith Shop
bot	Bottom
Br.	Branch
br.	Bridge
C.	Cape
cem.	Cemetery
con.	Concrete
cov.	Covered
Cr.	Creek
cul.	Culvert
d.	Deep
D.S.	Drug Store
E.	East
Est.	Estuary
f.	Fordable
Ft	Fort
G.S.	General Store
gir.	Girder
G.M.	Gristmill
i.	Iron
I.	Island
Jc.	Junction
k.p.	King Post
L.	Lake
Lat.	Latitude
Ldg.	Landing
L.S.S.	Life Saving Statior
L.H.	Lighthouse
Long	Longitude
Mt.	Mountain
Mts.	Mountains
N.	North
n.f.	Not Fordable
P.	Pier
pk.	Plank
P.O.	Post Office
Pt.	Point
q.p.	Queen Post
R.	River
R.H.	Round House
R.R.	Railroad
S.	South
s.	Steel
S.H.	Schoolhouse
S.M.	Sawmill
Sta.	Station
st.	Stone
str.	Stream
T.G.	Tollgate
Tres.	Trestle
tr.	Truss
W.T.	Water Tank
W.W.	Water Works
W.	West
w.	Wood
wd.	Wide

CHAPTER IV

THE FORM OF THE GROUND

Degree of Slope

THE SLOPE of the ground is the angle between the surface of the ground and a horizontal line. In military work this angle is measured in degrees and is called the "degree of slope." A rise of one unit in 57.3 units (horizontal) is a one degree slope. A rise of 2 units in 57.3 units is a two degree slope. Up to about 20 degrees this method is quite accurate. In ordinary engineering practice the slope angle is measured in percent. It is the number of units rise divided by the horizontal distance in the same units. A rise of 1 foot in 100 feet is a 1% slope.

A steep slope is one with a large angle between the surface and the horizontal, and a gentle slope is one with a small angle. An even slope is one where the angle is constant, and an uneven slope is one where the angle changes. A level piece of ground is one which has the same elevation at all places. A flat piece of ground is not necessarily level,—the surface of a board for instance is flat in any position. The terms valley, ridge, gulley, etc., are well enough known so description here may be omitted.

There are two methods used on maps for showing the form of the ground. The most common is the Contour method, and the other, now very seldom used except on very small scale maps, is the Hachure method.

Contours

Contours should be thought of as lines cut from the earth by a series of imaginary level surfaces, with **equal vertical distances between them.** The French call them "courbes horizontales representant le terrain." The vertical distance between the imaginary surfaces is called the "Contour Interval" or sometimes the "Vertical Interval." (Abbreviated C. I. or V. I.) Since a contour is a line in a level surface, all points on it are of the same elevation — or **contours are lines joining points of the same elevation.**

Contour Interval

Fig. 2 represents a conical hill, with a gulley down one side. The first imaginary surface passes thru points which are 5 feet above the bottom of the hill. It will cut out a line, shown on the map below, which represents points which are 5 feet above the bottom of the hill. The next surface is 10 feet above the bottom of the hill, and cuts out a line which shows places 10 feet higher than the bottom. The map can only show the horizontal distance from X to Z, but at point Y one can tell that the ground is 5 feet higher than it is at X, because all points on that line are 5 feet above the bottom of the hill.

The slope of the hill is even—the angle between the surface and a horizontal line is always the same. Since the surfaces are equally spaced, angle ACB (See Fig. 2) is equal to angle CDC′, angles CC′D and ABC are right angles and side AB equals side CC′, so triangles ABC and CC′D are equal and side CB is equal to side DC′. Therefore, it is seen that the horizontal spaces between the lines cut out by the surfaces (the contours) are the same, **where the slope is even.**

This horizontal space **on a map between the contours** is called the "Map Distance."*

Map Distance

This establishes the first principle of contours: (1) WHERE THE CONTOURS ARE EVENLY SPACED, THE SLOPE IS EVEN.

Fig. 3 represents a hill shaped lige a semi-sphere. Near the bottom where the slope is steep the lines cut out by the

* The term "Map Distance" is seldom used in any other sense.

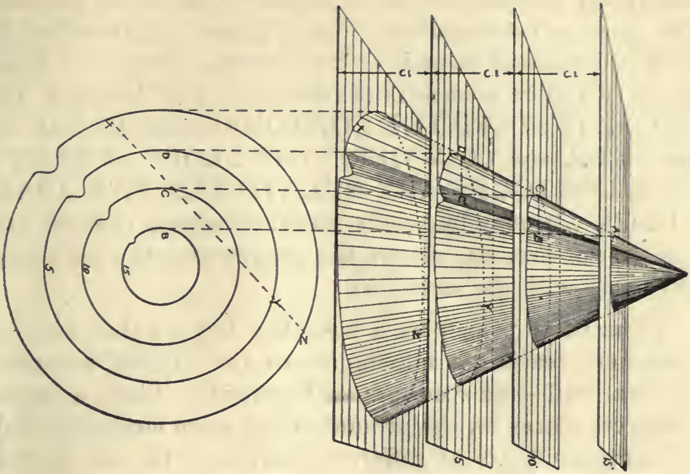


Figure 2

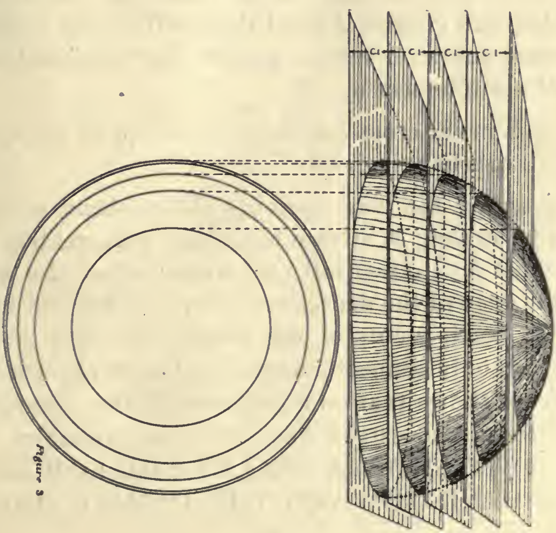


Figure 3

imaginary surfaces are closer together than at the top where the slope is more gentle. Fig. 4 shows a reversal of this form—the gentle slope is at the bottom. These two figures show two more principles of contours: (2) WHERE THE SLOPE IS STEEP THE CONTOURS ARE CLOSE TOGETHER, and (3) WHERE THE SLOPE IS GENTLE THE CONTOURS ARE RELATIVELY FAR APART. (1), (2), (3), may be briefly stated by saying that the spacing of the contours shows the degree of slope by varying inversely with the steepness.

From these principles it naturally follows that when the steepness reaches a maximum—or the ground becomes a vertical cliff—the contours will coincide. Since a contour connects places on the ground of the same elevation, if two or more contours of different elevations lie one over the other it means that places of different elevation on the ground exist one vertically over the other. On the other hand when the ground is level there will be no contours at all, because one level surface passed over another level surface will not intersect it.

Contours never cross one another, except in the very rare case of an overhanging cliff.

Fig. 5 shows the way contours always bend toward the source of a stream. A stream must have a depression to flow in and must flow down hill. Therefore when the contours get to the edge of the depression, they will have to bend upstream to reach points of the proper elevation, because a contour can only connect places of the same elevation. The same figure shows that on a ridge or hill the contours bend down stream, and establishes two more principles of contours: (4) TO SHOW A VALLEY THE LOWER CONTOURS BEND TOWARD THE HIGHER ONES, and

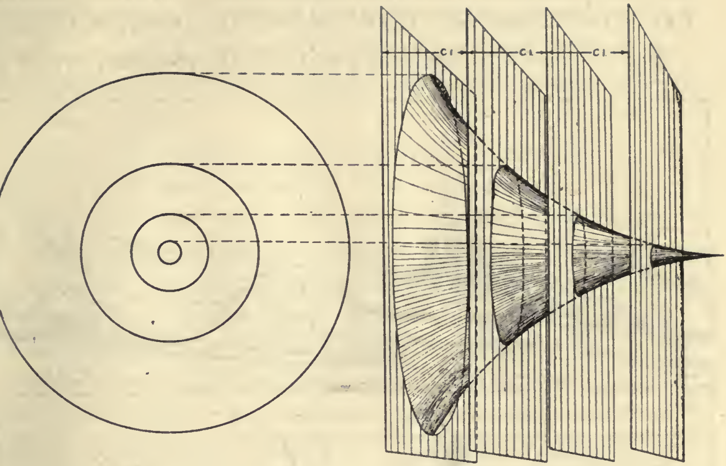


Figure 4

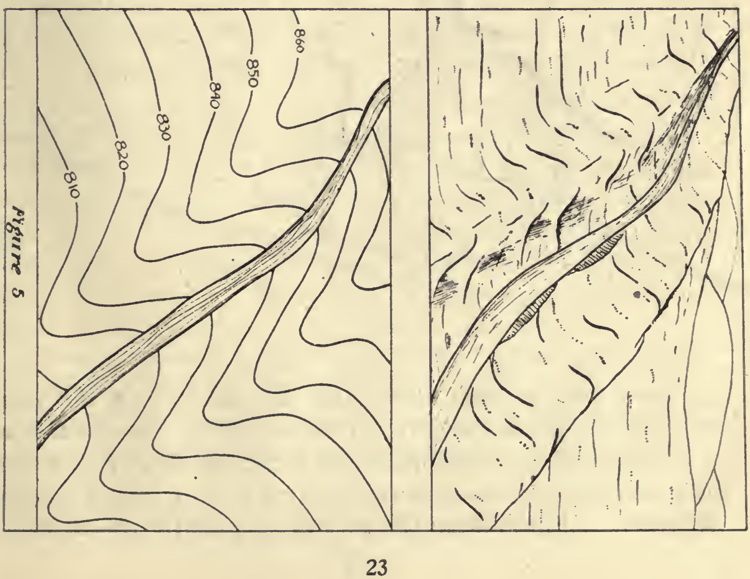


Figure 5

(5) TO SHOW A HILL OR RIDGE THE HIGHER CONTOURS BEND TOWARD THE LOWER ONES.

Fig. 6 shows a landscape with hills, streams, steep and

Figure 6.

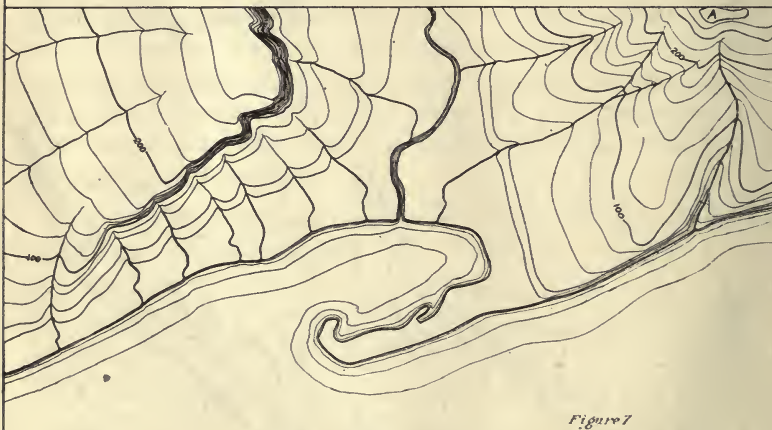


Figure 7

gentle slopes, vertical cliffs, and flat places, and the map below it shows the way it is represented by contours.

It is sometimes possible to get a clearer idea of contours by imagining a contour to represent the shore line of a body of water. All points on the surface of a still body of water are of the same elevation, so the conditions of a contour are satisfied. Now imagine the surface to be lowered a certain amount. It is apparent that where the ground is steep the new shore line will be closer to the old than at a place where the slope is gentler.

Contours are usually drawn in brown. When you decide to make a map, you choose the contour interval as soon as you have fixed the scale. Suppose you decide to have a contour for every 20 feet of elevation: Then the first contour on the map if you are mapping country near the sea, will pass thru points 20 feet above mean sea-level. (Mean sea-level is usually chosen as reference or datum.) The next one will pass thru points 40 feet above the sea, the next thru points 60 above, etc. It is customary to number only every fourth or fifth contour—in the U. S. generally every 5th—and those bearing the numbers are made several times heavier than the others. If the C. I. is 10 feet, the 50, 100, 150, etc., contours will be numbered and heavy. If the C. I. is 20 feet, the even hundreds will be numbered and heavy.

Having only a few of the contours numbered sometimes makes it difficult to tell whether several concentric contours represent a hill top or a depression. See A, Fig. 7. Unless there is some information to the contrary, it is safe to assume that such a feature is a hill top. Depressions are shown sometimes by drawing short lines perpendicular to the contours, on the inside. Sometimes the exact elevation of the deepest and highest points are shown in figures.

On some French maps, none of the contours are numbered. Prominent points have their elevations shown in figures and the contours simply show the form. Their elevations must be figured from the elevations of the nearest known points.

Contours, being cut out by surfaces passed thru the earth, are closed lines and therefore contours never end on a map. They either close on themselves, or run off the map.

Since a 1° slope is a rise of 1 unit in 57.3 units horizontally, the slope (S), in terms of horizontal distance (D) and difference in elevation (H), may be stated:

$$S = \frac{H}{D} \times 57.3$$

i. e., if we had a 4 foot rise in 114.6 feet, we would have a 2° slope. But contours are lines on a map, and it is more convenient to use the "map distance" (Page 20) and "contour interval" when working out slopes from a map. The map distance (M. D.) is equal to the ground distance (D), times the R. F. (See Page 5). Letting "H" in the above formula be limited to one contour interval, and since D = M.D./R.F.:

$$S \times D = H \times 57.3$$

$$S \times \frac{M.\,D.}{R.\,F.} = C.\,I. \times 57.3$$

$$S \times M.\,D. = R.\,F. \times C.\,I. \times 57.3$$

It is convenient to measure M. D. with a ruler graduated to inches or centimeters and to use the C. I. in feet or meters as given on the map. In the English system the formula becomes: (Since 12″ = 1 foot)

$$S \times \frac{M.\,D.\ (\text{in inches})}{12} = R.\,F. \times C.\,I.\ (\text{in feet}) \times 57.3 \text{ or}$$

(1) $S \times M.\,D.\ (\text{inches}) = R.\,F. \times C.\,I.\ (\text{feet}), \times 688$
$(57.3 \times 12 = 688)$

In the metric system, (since 100 cm. = 1 meter)

$$S \times \frac{M.\,D.\ (\text{in cm.})}{100} = R.\,F. \times C.\,I.\ (\text{in meters}) \times 57.3$$

or (2) $S \times M.\,D.\ (\text{cms.}) = R.\,F. \times C.\,I.\ (\text{meters}) \times 5730$

If two adjacent contours are ¼ inch apart on a map whose scale is 4 inches = 1 mile, C. I. = 15 feet, the slope may be found as follows:

$$S \times \tfrac{1}{4} = \frac{1}{15840} \times 15 \times 688$$

$$S = \frac{4 \times 15 \times 688}{15840} = \frac{688}{264} = 2.6^\circ$$

To find the distance apart in centimeters the contours will be on a map whose scale is 10 cm. = 1 km., C. I. = 3 meters, for a 4° slope:

$$\text{M. D.} \times 4 = 1/10000 \times 3 \times 5730$$

$$\text{M. D.} = \frac{3 \times 5730}{4 \times 10000} = 0.42 \text{ cm.}$$

Some maps have a "Map Distance Scale" which may be used to find the slope graphically. The scale is made by using the formula to find the M. D. for several different degrees of slope.

Normal System of Map Scales

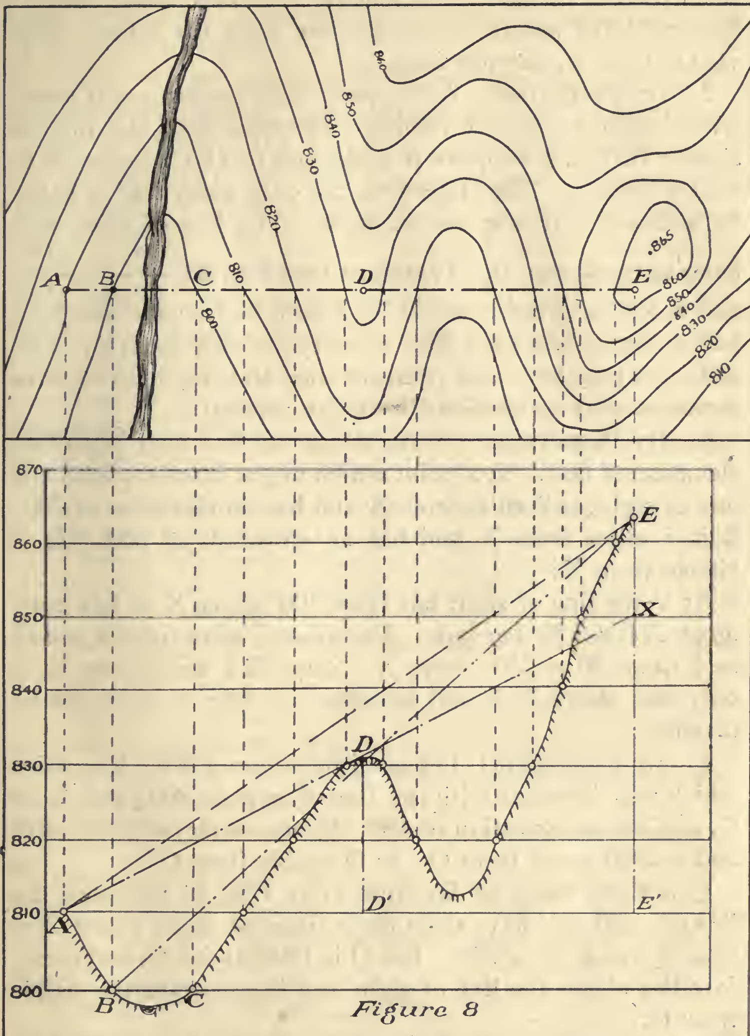
The normal system of map scales prescribed by the U. S. Army for field sketches is based upon the above formula. The spacing of contours for a 1° slope is 0.65 inch. After the scale of the map is decided upon the proper C. I. is found from the formula, since all the quantities except the C. I. are then known. The spacing for a 2 degree slope is 0.32 inch, for a 3 degree slope 0.22 inch, etc. This is of great value in teaching men to read maps in the field, because the same contour spacing means the same slope on all maps no matter what their scale, if the C. I. is chosen according to the Normal System. A simple rule to remember is that if the C. I. = 60 ÷ scale of the map in inches per mile, the map is in the Normal System, i. e., Scale 6 Inches = 1 Mile. C. I. = 10 feet (60 ÷ 6 = 10).

The Profile It is sometimes desirable to know the form of the ground along some definite line. A drawing which gives this information is called a profile. It is made from a contour map by taking a sheet of paper with equally spaced parallel lines, and numbering the lines according to the contour interval, starting with the number on the lowest contour along the line under consideration and continuing to the highest. This sheet is placed along the line on the map (Fig. 8). The line crosses the 810 contour at (A). Drop a perpendicular from (A) to the line numbered 810. The line crosses the 800 contour at (B). Drop a perpendicular from (B) to the line numbered 800. Continue this throughout the length of the line of which a profile is desired and connect up the points so found with a smooth curve and the exact form of the ground will be shown. A study of the profile and map will show that the map simply shows the horizontal distance between two points, while the profile shows the true distance (of course to scale).

(The sheet of parallel lines need not be parallel to the line of which the profile is desired, as long as the perpendiculars are dropped to them. If they are askew, it will have the effect of making the scale smaller, but the relations will remain the same. For the same reason the spacing of the lines is immaterial.)

Visibility It is very desirable to know at times whether one point is visible from another or whether a certain line of march is concealed from the enemy, etc. This information may be easily obtained from a contour map in several ways:

1. The Profile Method. (Fig. 8.) Draw a profile of the ground between the points in question and then draw a straight line from one point to the other. This line repre-


840
850
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D
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850
840
830
820
810
800
E
X
D
D'
E'
A
B
C

Figure 8

sents the line of sight. See whether it passes thru a hill. If it doesn't the points are visible one from the other. E is visible from A, but not from B.

2. By Proportion: An inspection of the map will show which high points are liable to interfere with the line of sight. In Fig. 8 suppose it is desired to find whether E is visible from A. The ridge D is the only point that is liable to interfere with the line of sight. The line of sight will have to pass over D. Therefore (see Fig. 8) $\frac{XE'}{DD'} = \frac{AE'}{AD'}$, and if XE′ is greater than EE′, E will be invisible from A; and if XE′ is less than EE′, E will be visible from A. The distances may be scaled from the map and the differences in elevation may be obtained from the contours.

3. By Proportion: From a map we find that X has an elevation of 600′. Y, a point which might interfere with the line of sight, is 2 miles from X and has an elevation of 700′. Z is 5 miles from X and has an elevation of 800′. Is Z visible from X?

At Y the line of sight has risen 100′ above X or has gone up at a rate of 50′ per mile. Therefore 5 miles from X it will be 5 times 50 or 250′ above X. Since Z, 5 miles from X, is only 200′ above X, it will lie below the line of sight and be invisible.

4. By Proportion: O has an elevation of 200′. P, a point which may interfere with the line of sight, is 800 yards from O, and has an elevation of 450′. Q has an elevation of 1400′ and is 2400 yards from O. Is Q visible from O?

Q is three times as far from O as P is, so therefore the line of sight will have risen three times as much above O at Q as it was at P, or 750′. But Q is 1200′ above O, and therefore lies above the line of sight and is consequently visible from O.

If more than one high place exist along the line of sight they are taken one at a time until all are eliminated or one is found to interfere.

The second method of showing the form of the ground is the Hachure Method. It is very little used in the United States and most of the European countries have abandoned it. However, it is still used to a very slight extent on small scale maps, particularly in Germany. A contour map gives not only exact elevations but a much clearer idea of the ground form than a hachured map. The spots on a hachured map where no hachures are found are either the tops of hills or flat, low places. It is often very difficult to tell the flat areas without reference to other features nearby. The steepness of the slope is roughly indicated by the varying blackness and nearness of the hachures. As a rule, figures show the heights of important points in feet or meters.

PROBLEMS ON SLOPES AND VISIBILITY

1. The scale is 6″ = 1 mile, C. I. = 10 feet. The 910 contour is 0.32″ from the 920 contour. What is the degree of slope? Answer, 2°.
2. What is the M. D. on a map whose scale is 4″ = 1 mile, C. I. = 20 feet, for a 5° slope? Answer, 0.17″.
3. What is the M. D. on a map whose scale is 3″ = 1 mile, C. I. = 20 feet, for a 6° slope? Answer, 0.11″.
4. Scale is 12″ = 1 mile, C. I. = 10 feet. If the 800 contour is ½″ from the 810 contour, what is the degree of slope? Answer, 2.6°.
5. Elevation of A is 200′. B, in line with A and C, is 3 miles from A, elevation 400′. C is 9 miles from A, and its elevation is 1000′. Is C visible from A? Answer, Yes.
6. In Problem 5, how high could C be, and still be invisible from A? Answer, 799′.
7. Elevation of A is 800′. B is 2 miles from A, elevation 1000′. C is 5 miles from A, elevation 1500′. D is 9 miles from A, elevation 1900′. (A, B, C, & D are all in line.) Is D visible from A? Answer, No, C interferes.
8. The scale of a map is 5 cm. = 1 km. C. I. = 5 meters. What are the M. D.'s for the following slopes: (a) 1°? (b) 3°? (c) 4°? (d) 6°? (e) 9°? Answers: (a) 1.43 cm., (b) 0.48 cm., (c) 0.36 cm., (d) 0.24 cm., (e) 0.16 cm.

CHAPTER V

DIRECTION

WHEN AN aviator wanted to make a cross country flight in the early days of flying, he usually made arrangements to have a special train (engine and caboose), with a white sheet behind, to guide him, or he at least followed a regular train. But when one is flying over the enemy's country he won't find a train to guide him and probably not even railroad tracks running to the places he wants to see. He must keep his direction by a compass, the stars or the sun, and a map. Side winds cause the plane to drift out of its course and the compass is liable to be disturbed by local magnetic influences, such as metal in the plane, electrically charged clouds, magnetic ore deposits, etc. Therefore, the aviator must know how to keep his course and check his progress by the use of his map.

Orientation It must be remembered that from a great height in the air a large number of objects can be seen. For this reason, at times it is very difficult to identify particular places on the map, but if one notes carefully the directions of railroads, highways, streams, forests; the angles of intersection of railroads and highways; and the bends in streams, railroads, and highways, and so forth, he can locate his position by finding a similar place on his map. To be able to do this quickly it is necessary to have the map in such a position that the lines on the map are parallel to the lines they represent on the ground. When a map is in this position it is said to be ORIENTED. Then it represents the ground in miniature—North of map is North on ground, South of map is South on ground, etc. A map should never be used without first orienting it, because it not only saves time, but greatly reduces the possibility of error.

The top of the map is almost always north—the printing reads from west to east. It is usual to have a prominent arrow labelled "Meridian" or "True Meridian" (Fig. 11) to show the direction of north, especially in the rare cases where the top of the map is not north. In addition to this, maps are usually divided by horizontal and vertical lines, lines of longitude and latitude, in which case the true north is the direction of the longitudinal lines, or by lines which divide the map into conveniently sized squares for reference in artillery work. On a complete military map an arrow, less elaborate, usually, will be found, at an angle with the true meridian, which shows the direction the compass needle points in that locality, the angle being the angle of variation. (See Page 39.) This arrow is labelled "Magnetic Meridian."

Orienting by Compass

The easiest way to orient a map is to turn it till the line showing the **magnetic north** is parallel to and pointing in the same direction as the compass north-south line. This will make one line on the map parallel to the line it represents on the ground and therefore all the lines on the map will be parallel to the lines they represent.

Orienting with Watch

Without a compass the map may be oriented in the daytime with the aid of a watch. Take the number of hours since midnight, and divide by two. Hold the watch face up, in such a position that a line from the center thru the resultant hour will point toward the sun. Then a line thru the center and the figure "12" will point north, i. e., it is 4 P. M., 16 hours since midnight. Point the figure 8 at the sun and the figure 12 will be north. (See Fig. 10.) It may be easily done with the watch strapped to the wrist. If an accurate determination is desired, a string with a weight on one end may be held so it casts a shadow across the face of the watch and the watch turned till the proper hour and the center of the watch are in the shadow. After the north is found, the map is oriented by pointing a line on the map which is known to be a true N-S line toward the north.

Orienting by Stars

At night without a compass the map may be oriented by the stars. The North Star is easily located by its relation to the Big Dipper, Casseopia, or the Little Dipper. (See Fig. 9.) If a line on the map which is known to be N-S is pointed toward the North Star the map is oriented.

Orienting by Known Points

The more usual methods of orienting are by lining up the symbols on the map with the features they represent on the ground. For instance, a long straight highway is seen on the ground and the symbol for it is easily found on the map. If the map is turned so that this symbol is parallel to the road, it is oriented. (Care must be taken not to turn the map thru 180 degrees, by checking by other features in the vicinity.) If two prominent hills can be seen and the symbols for them found on the map, the map is turned so that an imaginary line between the symbols on the map is parallel to an imaginary line between the hills on the ground.

When one is on the ground, if his position is known, the map may be oriented by sighting along the map, over the symbol for his position and the symbol for some other feature, and turning the map till the second feature is seen as he sights over the two symbols. If his exact position is not known but two objects can be seen in line, the map is turned so that a line of sight across the symbols for the two objects passes thru the two objects on the ground, and it is oriented.

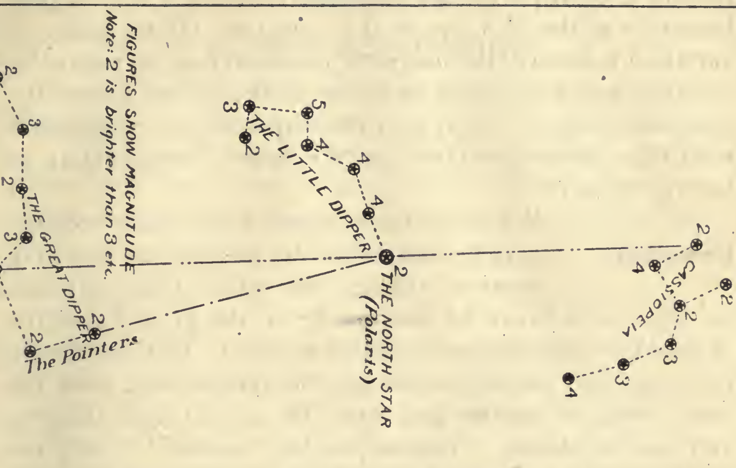


Figure 9.

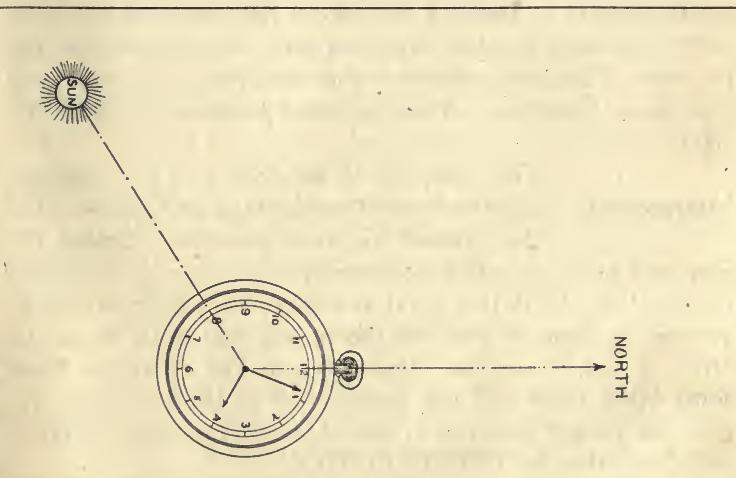


Figure 10.

After a map has been oriented by some method, the magnetic meridian may be put on, if it is not already there, by placing a compass on the map and drawing a line in prolongation of the N-S line of the compass. (If the angle of variation is known, the magnetic meridian may be put on by drawing a true N-S line, and putting the lubber line of the compass along it. Then turn the **map** with the compass on it till the lubber line points to the figure corresponding to the variation.)

Resection When on the ground, one's exact position may be located on the map in the following manner: Orient the map. Then pick out an object which can be seen easily on the ground and the symbol for which can be found on the map. Hold a ruler on the map with its edge touching the symbol, and turn the ruler, using the symbol as a pivot, till, as you sight along it, you see the object. (The map is kept oriented during the entire process.) Draw a line along the ruler toward your body. Pick out another object on the ground and repeat the process. The point at which the two lines cross will give your exact position. This is called location by RESECTION.

Intersection The position of an object in the distance may be located on the map as follows: Find the symbol for your position. **Orient** the map and lay your ruler on the map with its edge touching the symbol. With this point as a pivot turn the ruler till as you sight along it you see the object you wish to locate. Draw a line along the ruler. Repeat the operation **from some other point** and the intersection of the two lines will give the proper position of the object in question. This is called location by INTERSECTION.

CHAPTER VI

AERIAL NAVIGATION

Bearings

TO DESCRIBE the direction or bearing of a line in aviation work, the angle, measured clockwise from the north, which the line makes with a north-south line, is given. This angle is measured with a protractor, a semi-circular instrument graduated in degrees from 0° to 180°, and also from 180° to 360°. (Fig. 11.) To find the bearing of a line a meridian or north-south line is drawn thru the initial point. If the line lies to the east or right of the meridian, the protractor is placed to the right with its back along the meridian and its center over the initial point. The graduation on the arc between 0° and 180°, under which the line passes, is the bearing. The bearing of line AB is 135°, and of AC is 47°. If the line lies to the west or left of the meridian, the protractor is placed to the left, with its back along the meridian and its center over the initial point and the graduation on the arc between 180° and 360° under which the line passes is the bearing. The bearing of XY is 195° and of XZ is 315°.

In navigation in the air or on sea, one usually speaks of the bearing of the line along which he is travelling as his "course." In engineering practice the bearing is sometimes spoken of as the "azimuth."

It is better to speak of a true north course as 360° instead of 0°.

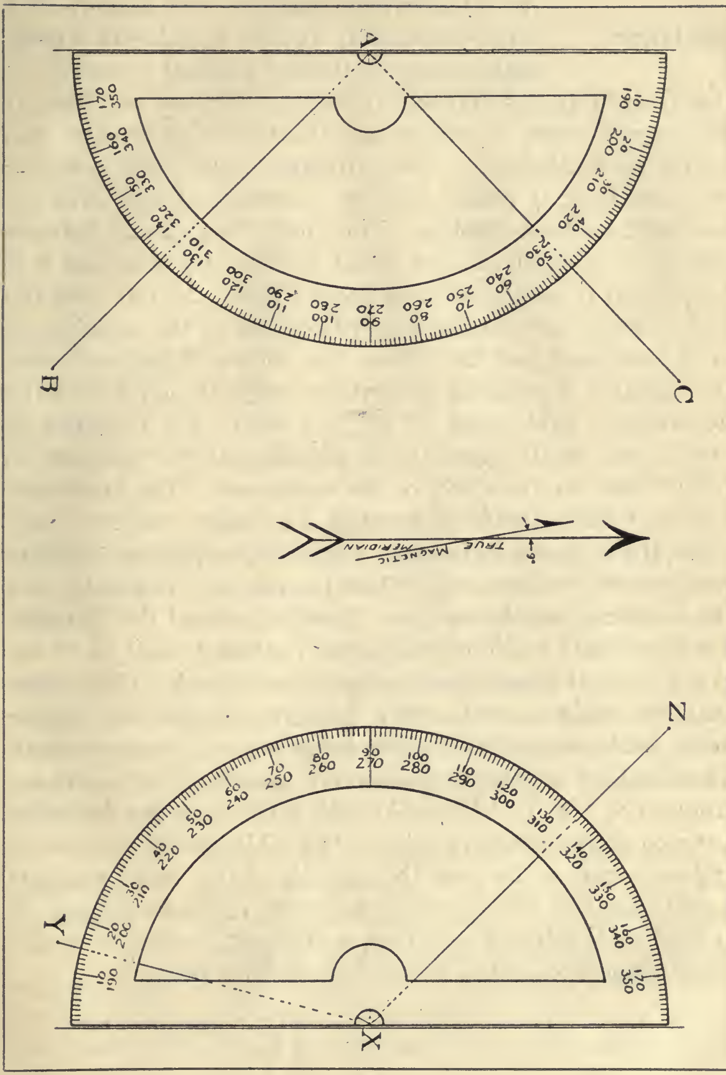
Variation

The magnetic compass does not always point toward the true or geographic north. This is because the magnetic north pole is located considerably to the south of the geographic north pole. The VARIATION of the compass, or the angle between the direction the compass points and the true north is different for different parts of the world. In the state of Washington the compass needle points over 20 degrees east of north, points true north in some parts of Michigan, and over 20 degrees west of north in Maine. The variation also varies slightly from year to year. Maps are published showing the variation in different parts of the country. They have lines on them called "**Isogonic**" lines which connect all points which have the same variation. A line on such a map which connects points where the variation is zero, or where the compass points true north, is called an "**Agonic**" line.

Isogonic and Agonic Lines

The ordinary compass has a needle which moves over a dial, and when one wishes to find his direction the box is turned till the north-south line is directly under the needle. The airplane compass has its needle fastened to the dial, which moves under an indicator. This indicator is called the "lubber line." The compass is mounted in the plane in such a manner that when the longitudinal axis of the plane is north-south, head of the machine north—the lubber line is directly over the N or 360 of the compass dial. If the plane is pointed northeast, or 45°, the dial does not move, because it is fastened to the needle, which always points to the magnetic north, but the lubber line moves along till it is over the 45 degree mark of the dial. The aviator can always tell the direction his machine is pointing by finding which figure the lubber line of his compass is pointing to.

The air compass is subjected to a second error, caused by the proximity of the metal parts of the machine. This error is called deviation, and is different for each direction the machine is pointed, and for each machine and compass.


A
B
C
X
Y
Z
TRUE MERIDIAN
MAGNETIC
9°

Deviation At places where machines are assembled a large platform is usually found with a **magnetic** north-south line marked across it; a line at right angles to it which is east-west; and two lines at 45 degrees with it which are northwest-southeast, and northeast-southwest. The airplane, with its compass mounted in it, is placed with its longitudinal axis over the magnetic north-south line. The lubber line should indicate 360 or N. But due to the metal parts of the machine it is found that it points to some other figure. In this case the dial is drawn toward the west 10 degrees by the metal parts of the machine, and the lubber line shows 10 degrees when the machine is pointing toward the magnetic north, and the deviation is said to be 10 degrees west. (If the error is very large, small magnets are placed near the compass to compensate for the effect of the machinery. The error cannot be totally removed because too many magnets may effect the compass differently when the machine is pointing in some other direction.) Then the machine is placed over the northeast-southwest line. Now it is found that the lubber line points to 36 degrees when it should point to 45 degrees, since the machine is pointing northeast. This shows that the dial has been drawn 9 degrees to the east by the metal parts, so the deviation for this point is 9 degrees east. The machine is placed successively in each of the eight positions (N, NE, E, SE, S, SW, W, NW), and the deviation for each point noted in a table. (The table should be checked at least once, to be sure the placing of the small magnets hasn't changed the deviation for some previous point.) A typical table follows, which of course only applies to a particular machine with a particular compass in it:

TABLE III

1 Direction Plane Points	2 Magnetic Bearing or Direction Compass ought to show.	3 Compass Bearing or Direction compass actually shows	4 DEVIATION
N	360	10	10W
NE	45	36	9E
E	90	88	2E
SE	135	150	15W
S	180	185	5W
SW	225	215	10E
W	270	267	3E
NW	315	317	2W
N	360	10	10W

(Column 3 is not always given.)

Map, Magnetic, and Compass Courses

When a bearing is taken from a map and referred to a true north-south meridian, it is called the "Map Course." When this bearing has been corrected for the variation in the region, or in other words, when it refers to the angle made with the magnetic meridian, it is called the "Magnetic Course." When it has been corrected for deviation, or when the bearing is the reading the compass must have to keep the plane going in the proper direction, it is called the "Compass Course."

Correction for Wind

Before the conversion for compass work is made, the correction to the map course for the wind is figured out. The wind causes the plane to drift out of its course an amount per hour equal to the velocity of the wind, and in the direction the wind is blowing. For instance, if one wanted to fly from east to west, and a wind was blowing 30 m.p.h. from the north, at the end of one hour the plane would be 30 miles south of the line along which the aviator wanted to fly, unless he made allowance for the wind. To counteract this wind effect, the pilot must "crab" his machine into the wind. The amount of correction is usually found graphically from the map. Suppose it is desired to fly from A to B in Fig. 12. The map course or track is 90 degrees. The wind is blowing at a rate of 25 m.p.h. from the northwest. The air-speed of the plane is 75 m.p.h. Choose some unit, say M, Fig. 12, to represent 5 m.p.h. Beginning at A, lay off a line from northwest to southeast, or 135 degrees, and on it mark out 5 times M, or 25 m.p.h. This line represents the velocity and direction of the wind. In other words, the end of the line will be the point to which the plane would be blown at the end of an hour if it made no progress in the direction AB. Let this point be called P. Now, with P as a center, and radius of 15 times M or 75 m.p.h., describe an arc cutting AB in C. A line from A (AX), parallel to PC, will show the direction in which the plane will have to be pointed in order to keep on its course. The actual flight of the machine will be along the line AB. The corrected map or heading course is then 76° The rate of progress along the line AB can be found by measuring AC and finding how many times M is contained in it. In this case it is 18 + x M, and since M is 5 m.p.h., the rate of progress is 91 m.p.h. To find the length of time required to get to B, divide the distance AB by 91. To get back from B to A, the uncorrected course is 270, the wind direction 135 as before, and a new chart is constructed with the data.

The direction of the wind is obtained from a weather vane on the aerodrome, and its velocity from an anemometer. It must be remembered that at higher altitudes there is a tendency for the velocity of the wind to increase and for its direction to change.

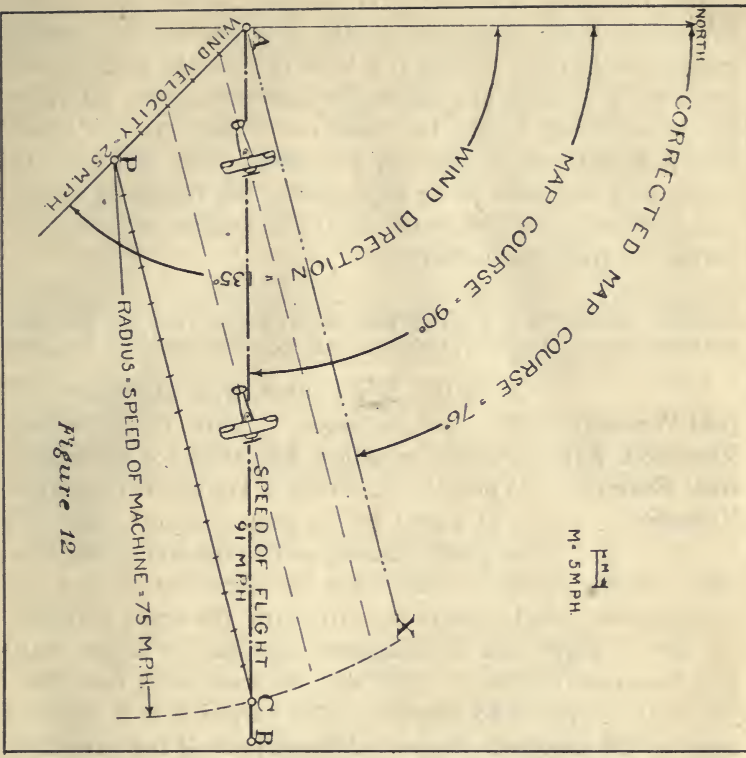


Figure 12

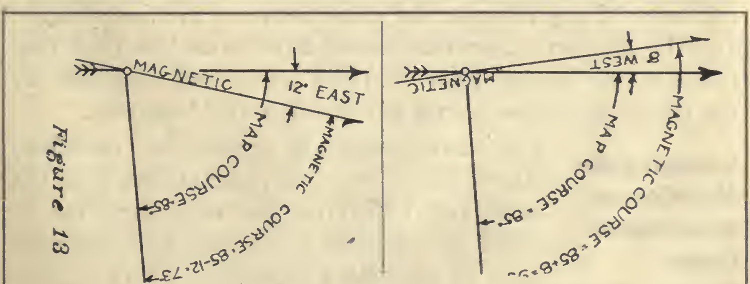


Figure 13

The following table will give an approximate idea of the prevailing wind velocities in the latitude of the United States and France. There is a tendency for the direction of the wind to change in a clockwise direction as you go up in the lower flying levels, but local conditions vary so much that it is difficult to give any set rules. You will have to learn the conditions to be expected in the region in which you are flying, but you must always be careful to watch for variations from the ordinary.

Height in Feet		900	1300	2000	2600	5600	6600	7900	9800	10500	13100	16400
Velocity in Miles per hour	Summer	6.5	8.4	10.5	10.5	10.5	11.2	13.0	15.9	16.8	20.4	24.4
	Winter	10.3	11.7	13.2	14.3	14.8	15.2	18.8	18.8	19.2	22.4	26.4

Add Westerly Variation, Subtract Easterly Variation

After the map course, with allowance for the wind, is found, it must be corrected, first for variation, and then for deviation. When the variation is known, if it is west it is added to the map course to get the magnetic course, and subtracted when it is east. Figure 13 shows that when the variation is west, or the magnetic needle points west of north, the angle between the line of flight and the magnetic meridian is larger than that between the line of flight and the true north meridian. The map course is 85 degrees. The variation is 8 degrees west, so the magnetic course is 93 degrees. If the variation had been 12 degrees east, the angle between the line of flight and the magnetic meridian would have been less than that between the line of flight and the true north meridian, or the magnetic course would have been only 73 degrees.

Changing the Map Course to Compass Course

The same reasoning applies for deviation errors, but it must be remembered that the deviation is different for each direction in which the machine is pointed, and therefore must be calculated separately for each case.

The following problems illustrate the method usually used for finding the compass course from the magnetic course.

PROBLEM 1: The map course, corrected for wind, is 35°. The variation is 10° west. What is the compass course?

Since the variation is west it is added to the map course to get the magnetic course. This makes the magnetic course 45°. From Table III it is found that when the machine is pointing in a direction 45° from magnetic north, its compass is drawn 9° toward the east. Then to get the compass bearing, the deviation must be subtracted from the magnetic course. Then the compass course is 36°. This means that when the compass in the machine shows 36°, the plane is really headed in a 45° line (Mag.). In other words, to fly a map course of 35° in a locality where the variation is 10° west, with this particular machine, the compass must read 36°.

PROBLEM 2: The map course, corrected for wind, is 145°. The variation is 5° west. What is the compass course?

The variation being west, it is added to the map course, to get the magnetic course, which becomes 150°.

Table III does not show the deviation for 150°, but it gives it for 135°, and for 180°. At 135° it is 15° west, and at 180° it is 5° west. In other words, between 135° and 180°, magnetic, the deviation has changed 10°. We can assume that the deviation has varied at a uniform rate, or (since $180 - 135 = 45$) at a rate of 10/45 or 0.22° per degree change in magnetic bearing. Since at 150° the magnetic course is 15° more than it is at 135°, the deviation will have changed $15 \times 0.22 = 3.3°$ (It is difficult to read a compass even to the nearest degree, so fractions of a degree are dropped). Since the deviation is diminishing from 15° west, at a magnetic bearing of 135°, to 5° west, at a magnetic bearing of

180°, the deviation at 150° will be 15 — 3 = 12°. As the deviation is west, it is added to the magnetic course, and the compass course becomes 150 + 12 or 162°. The work may be neatly arranged as follows:

Map Course	145		
Variation	5 West		
Magnetic Course	150		
Point under 150 at which dev. is known	135	Deviation	15W
Point above 150 at which dev. is known	180	Deviation	5W
Change in deviation between 180 and 135			10

Change in deviation between 135 and 150

(A) (150 — 135) x 10/45 = 3.3

Since the deviation is diminishing from 135 to 180, at 150 it is 15 — 3 = 12 west. Therefore it is added to the magnetic course and the compass course is 162°.

(The deviation table shows the deviation for each angle of 45 degrees, so statement (A) may always be written: (Magnetic course — nearest 45 point below it) x (Change in deviation between nearest 45 degree points above and below magnetic course in question) /45 = change in deviation.)

PROBLEM 3: Map course, corrected for wind, 340°. Variation 5 degrees east. Find compass course.

Map Course	340		
Variation	5 East		
Magnetic course	335		
Point below 335 at which dev. is known	315	Deviation	2W
Point above 335 at which dev. is known	360	Deviation	10W
Change in deviation between 315 and 360			8 degrees

Change in deviation between 315 and 335:

$$(335 - 315) \times (10 - 2)\ /45 =$$
$$20 \times 8/45 = 160/45 = 3.5$$

The deviation is increasing from 2° west at 315°, to 10° west at 360°, so at 335° it will be between 2° west and 10° west, and as the change is 4°, at 335° magnetic, the deviation is 6° (2 + 4), and since it is west it is added to the magnetic course and the compass course is 335 plus 6 or 341°.

PROBLEM 4: The map course, corected for wind, is 30°. The variation is 5° west. Find the compass course.

Map course	30
Variation	5 W
Magnetic course	35

Point under 35 at which dev. is known	360	Deviation	10W
Point above 35 at which dev. is known	45	Deviation	9E
Change in deviation between 360 and 45			19

(The deviation decreases from 10 W to 0 and then increases to 9 E. Total change is therefore 19 degrees.)

Change in deviation between 360° and 35°:

$$35 \times 19/45 = 14.8 = 15°.$$

The deviation is decreasing from 10 W at 360 to 0 and then increases to the east. Therefore the deviation will have become zero and increased to 5° east by the time a magnetic course of 35 degrees is reached. (Change from 10° W to 0° is 10°, and then from 0° to 5° E is 5° more, so the total change is 15 degrees).

Since the deviation is east, it is subtracted from the magnetic course and the compass course becomes 35 — 5 = 30°.

Another Method

Another method of finding the Compass Course from the Magnetic Course which does not require the deviation to be figured, may be used:

PROBLEM 5: The map course, corrected for wind, is 150°. The variation is 5° west. Find the compass course.

The magnetic course is 155°. From the Deviation Table we find the compass course is 150° for a magnetic course of 135° and 185° for a magnetic course of 180°. In other words, for a change in magnetic course of 180 — 135 = 45°, there is a change of 185 — 150 = 35° in compass course. Therefore there is a change of $\frac{35}{45} = 4/5°$ in compass course per degree change in magnetic course. From this it follows that when the magnetic course has changed from 135° to 155°, or 20°, the compass course will have changed from 150° to [150° + (20 x 4/5 = 16)] = 166°. Therefore the compass course is 166°.

If we call: The compass course—"C"

The magnetic course—"M"

The nearest magnetic course in the table below "M"—"A"

The compass course corresponding to "A"—"B"

The compass course for the nearest magnetic course above 'M" in the table—"D"

Then:

$$C = B + \left[\frac{D - B}{45} \times (M - A)\right]$$

PROBLEM 6: The map course, corrected for wind is 200°. The variation is 10° west. Find the compass course.

"M" is 210; "A" is 180; "B" is 185; "D" is 215.

$$C = 185 + \left[\frac{215-185}{45} \times (210-180)\right]$$

$$= 185 + (30/45 \times 30) = 185 + 20 = 205°.$$

The compass course is 205°.

Changing Compass Course to Magnetic Course

It is sometimes necessary to change compass bearings to magnetic bearings and magnetic bearings to map courses. In aerial sketching, for instance, one method of getting the bearing of a line is to point the plane along the line, and then read the compass bearing. Being a compass bearing, it must be corrected before it is put on a map.

It is very simple to change magnetic bearings to map courses. When the variation is west it is added to the map course to get the magnetic course, and consequently it is subtracted from the magnetic course to get back to the map course. Similarly, variations east are added to the magnetic course to get the map course.

A slightly different method is followed to change from compass bearings to magnetic bearings than that used to change from magnetic bearings to compass bearings.

PROBLEM 7: The Compass course is 170°. Find the magnetic course.

From the table we find that for a magnetic course of 135°, the compass course is 150° (Deviation 15 W), and for a magnetic course of 180°, the compass course was 185° (Deviation 5 W). Or the compass course has changed 35° while the magnetic course changed 45°. Therefore the magnetic course has changed at the rate of $45/35 = 1\frac{1}{3}°$ per degree change in compass course. When the compass course is 170°, it has changed 20° (170—150), from the last point at which the magnetic course is known, so therefore the magnetic course will have changed $20 \times 1\frac{1}{3} = 27°$, from what it was when the compass course was 150° (135°), or the magnetic course is 162 degrees, when the compass course is 170.

Using the same abbreviations as on page 48, this statement may be made:

$$M = A + \left[\frac{45}{D - B} x(C-B) \right]$$

PROBLEM 8: The compass course is 30. Find the magnetic course.

"A" is 0; "B" is 10; "C" is 30; "D" is 36.

$$M = 0 + \left[\frac{45}{36-10} x(30-10) \right]$$

$$= 0 + (45/26 \times 20) = 0 + 35 = 35.$$

The magnetic course is 35, when the compass course is 30.

An excellent thing for the aviator to do if he has time is to plot the deviation against the magnetic courses, as shown in Fig. 14, or to plot compass courses against magnetic courses, as shown in Fig. 15. The first method is an easy one to find the deviation at all points, but it is believed that the latter is better because the compasss is found directly, and there is no adding or subtracting to be done. It is not necessary to bother to draw the curves smoothly, because in the first place there is not enough data to justify it and in the second place, a compass cannot be read closer than 1 degree and the straight line table will give results within 1 degree in most cases.

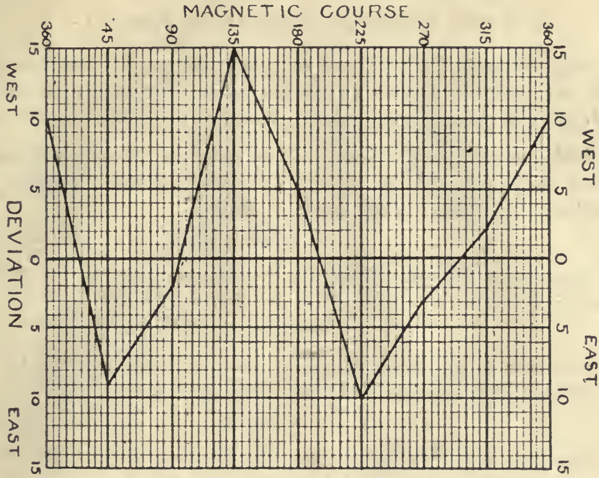


Figure 14

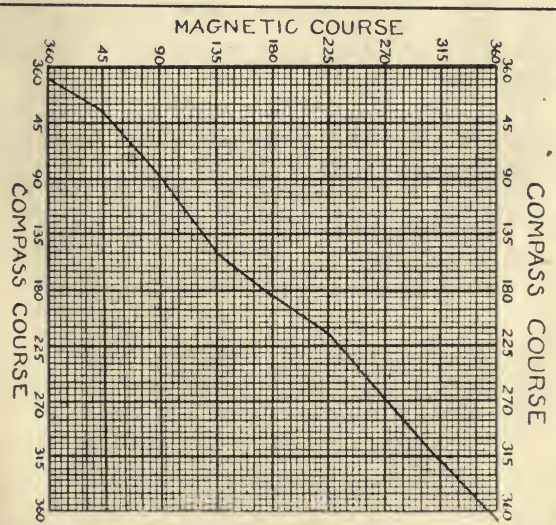


Figure 15

PROBLEMS ON BEARINGS

(Use table on page 41, or charts on page 51)

1. The map course is 150°. Speed of plane 100 m.p.h. Wind is from the northeast, 40 m.p.h. (a) What is the corrected map course? (b) What is the speed of flight? Answers, (a) 124°, (b) 102 m.p.h.

2. The map course is 285°. Speed of the plane is 120 m.p.h. Wind is from the southwest, 30 m.p.h. (a) What is the corrected map course? (b) What is the speed of flight?
Answers, (a) 273°, (b) 102 m.p.h.

3. The variation is 5° east. What are the compass courses for the following map courses: (a) 30°? (b) 150°? (c) 300°?
Answers, (a) 24°, (b) 157°, (c) 295°.

4. The variation is 10° west. What are the compass courses for the following map courses: (a) 40°? (b) 250°? (c) 315°?
Answers, (a) 42°, (b) 256°, (c) 329°.

5. The variation is O°. What are the compass courses for the following map courses: (a) 96°? (b) 230°? (c) 197°?
Answers, (a)96°, (b) 221°, (c) 197°.

6. The variation is 5° west. What are the map courses for the following compass courses: (a) 330°? (b) 210°? (c) 80°?
Answers, (a) 321°, (b) 212°, (c) 78°.

7. The variation is 8° east. What are the map courses for the following compass courses: (a) 285°? (b) 170°? (c) 25°?
Answers, (a) 294°, (b) 169°, (c) 33°.

CHAPTER VII

PREPARATION OF MAPS

Examining a New Map

A Regular method should be followed in examining a map which is new to you. The first thing to become familiar with is the scale. This will give you an idea of the detail of the information to be expected, the area the map covers, and enable you to make rapid mental calculations of the distances between points. If the scale is given graphically, become familiar with the spaces given. If it given in words and figures or in the natural scale convert it into units with which you are familiar. Remember, for instance, that "5 cm. = 1 km." is 1/20,000, which is approximately 3 inches to the mile.

Next find the contour interval. It is usually printed on the map ("Contour Interval 20 feet"; "L'Equidistance est de 5 metres"). If it isn't shown, find the numbers on the contours and take the difference, if every one is numbered; if every fifth one is numbered, divide the difference between the numbered ones by 5; if none are numbered, find the number of intervals between two places whose elevations are given, and calculate it. This will give you a relative idea of the differences in elevation—heights of hills and depressions of valleys.

Now examine the conventional signs, if a list is shown on the map. When such a list is given it is usually an indication that there has been a departure from the usually accepted standards.

Find which side of the map is north, the position of the true and magnetic meridians, and the amount of variation.

You are now in a position to make an intelligent use of your map.

If there is time, it will be found a great help to study the features shown on the map. Pick out the streams and follow them out. The streams are the framework of the country—they are put on the map first, and should be looked for first in forming an idea of the terrain. They show where the low places are, and then it is easy to imagine the approximate location of the hill tops and ridges. When the streams, ridges, and valleys are in mind, it is astonishing how quickly the features of the ground seem to stand out on the map. Pick out the towns and villages, and get their names and locations with respect to each other in mind. The railroads and highways should be traced out and their relative importance estimated.

Cross Country Flying

If the map is to be used for cross country flying, it will be of small scale. The course should be marked out on it, with the compass bearings written on the different lines. It will be found convenient if lines are drawn across the line of flight at intervals of about 10 miles. The scale will of course be too small for emergency landing fields to be picked from the map, so they should be found from maps of larger scale and marked on the map with the proper conventional sign. In this connection, remember that smooth, nearly parallel contours represent flat country, and rough uneven contours show country which is cut up by little ridges and valleys, because when a high contour bends toward a low one, there is a ridge, and where a low contour bends toward a high one there is a valley. A safe landing may be made on a slope of about 9 degrees, if the ground is smooth and flat, and such a place will be preferable to a field which is nearly level, but cut up with little bumps and depressions.

The features used for guides in cross country work are large woods, lakes, towns, highway intersections with railroads, highway and railroad intersections with streams, bends in large streams, and mountains or prominent hills. These landmarks should be marked with a heavy pencil and the approximate time they should be passed written near them. It is well, if color is not used on the map, to color either with grease pencils or ink, the woods in green, the highways in red, and the streams blue. Even if nothing else is done, it will be found a great help to have the streams colored, so they will not be mistaken for contour lines. A fountain pen will do for this in an emergency.

The map will usually be too large to be placed in the plane so it is all visible at once. For this reason it is necessary to cut it up into convenient-sized squares or rectangles.

The pieces are numbered, a north arrow marked on each, and the pieces mounted on cardboard or a continuous strip of cloth. If the first method is used, the cards are arranged so when the country represented on the first is passed over, the card is removed and the next in order is found under it and so forth. If the continuous strip method is used, it is arranged to roll from one roller to another, and the part with which you are finished is simply rolled up. It requires considerable practice to use a map cut up in such a manner, so the arrangement of squares should be carefully made.

Cooperation with Artillery

If the map is to be used for cooperation with artillery, it will be of large scale (1/20,000 or 1/40,000, sometimes even 1/10,000). The outline of the area to be observed should be marked out on it, the roads marked in red, the streams in blue, and the woods in green if they are not already colored. Fields of peculiar shape will be helpful if they are colored.

For work of this kind the reference points are fence corners, bends in small streams, corners of woods, highway intersections, small ponds, separate houses, and other small features which stand out well on the ground and are shown prominently on the map.

When the map is to be exposed in the plane in wet weather, a couple of coats of wing dope will make it waterproof, without producing any visible effect on the paper. Pencil marks may be made on this surface and erased without injuring the map.